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DEVELOPMENT OF A COMPUTER PROGRAM FOR THE DYNAMIC NONLINEAR RESPONSE OF REINFORCED CONCRETE SLABS UNDER BLAST LOADING

By

J. M. Ferritto

April 1976

Sponsored by

Picatinny Arsenal

CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California 93043

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A computer program was developed to determine the nonlinear dynamic response of reinforced concrete slabs subjected to blast pressure loading. Given the explosive parameters and geometry of the slab, the program computes the blast environment and the structural resistance, mass, and stiffness of the slab and solves for the dynamic response. The program will assist engineers in the design and analysis of facilities intended to contain the effects of accidental explosions. The report gives a user's guide and sample problems with data input and program output.

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A computer program was developed to determine the nonlinear dynamic response of reinforced concrete slabs subjected to blast pressure loading. Given the explosive parameters and geometry of the slab, the program computes the blast environment and the structural resistance, mass, and stiffness of the slab and solves for the dynamic response. The program will assist engineers in the design and analysis of facilities intended to contain the effects of accidental explosions. The report gives a user's guide and sample problems with data input and program output.

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INTRODUCTION

The Department of Defense (DOD) has numerous munitions facilities engaged in the production of the various types of explosives and munitions used by the military services. In most cases the production of ammunition utilizes assembly-line procedures. Projectiles pass through various stages of preparation; filling with explosive, fuzing, marking, and packing. Hazardous operations, such as the filling of the projectile case with explosive in a powder form and the compaction of the powder by hydraulic press, are accomplished in protective cells intended to confine the effects of an accidental explosion. Most of the existing production facilities were built in the 1940's. With few exceptions, the manufacturing technology and existing equipment represent the state-of-the-art as of 1940. The production equipment was operated extensively during World War II, again during the Korean conflict, and recently during the Southeast Asia war. Much of this equipment and the housing structures have been operating beyond their designed capacities [1]. DOD is conducting an ammunition plant modernization program approaching $4 billion with possible expenditures of $500 million a year [2]. The modernization program is intended to greatly enhance safety in the production plants by protective construction, automated processing, and reduction of personnel involved in hazardous operations.

In 1969 a tri-service manual [3] was published to provide guidance to the structural designers of munition plants. The objectives of the manual were to establish design procedures and construction techniques to prevent propagation of explosions from one building, or part of a building, to another; to prevent mass detonations; and to provide protection for personnel and equipment. The manual establishes blast-load parameters required for design of protective structures, provides methods for calculating the dynamic response of concrete walls, and establishes construction details to develop required strength. The design method used accounts for close-in effects of a detonation with its associated high pressures and nonuniformity of loading on protective barriers. A detailed method for assessing the degree of protection afforded by a protective facility did not exist prior to this manual's publication; consequently, the manual represents a significant improvement in design methods. The simplifications made in the development of the design procedures have been presented in the manual. The analysis of a structure using the design procedure will generally result in a conservative estimate of the structure's capacity; therefore, structures designed using these procedures will generally be adequate for blast loads exceeding the assumed load conditions [3].

Even with the simplifications presented in Reference 3 the computational procedures are complex and time-consuming. An automated procedure was required to give structural designers the capability to perform rapid analysis of the structural safety of blast-resistant construction.

OBJECTIVE

The objective of this work was to automate the analysis procedures for determining the dynamic structural response of reinforced concrete slabs having a bilinear stiffness representation and subject to blast overpressure. The concrete slabs are the basic element forming sidewalls, roofs, and floors of cells designed to confine the effects of accidental explosions.

COMPUTER PROGRAM

Description of Computer Program

The computer program was written in FORTRAN IV for use with Control Data 6600 series computers. The program consists of a main routine and 12 subroutines.

Main Program. The main program reads in the explosive weight and cell geometry. Subroutine EQUIV is called by the main program to compute the equivalent spherical weight of TNT, and then Subroutine PIC calculates the blast impulse acting on the slab. The main program determines the duration and pressure level of an equivalent triangular pressure loading using the geometry of the wall and charge location. The main program then calls Subroutine SSTIFF which determines the slabs resistance, stiffness, and equivalent mass. Having this information the program then determines the response of the slab modeled as an equivalent dynamic single degree-of-freedom system with bilinear stiffness and triangular pressure loading. The solution technique is based on the incremental solution of the differential equations of motion. The changing stiffness and loading are considered in the solution, and the maximum deflection and velocity are noted.

The thickness of sand is required as input data if the blast wall is made of composite construction having 2 slabs with sand fill. The program computes the impulse capacity of the first slab using half the mass of the sand as acting with the wall. Figures 6-38 and 6-39 of Reference 3 give the attenuation of the blast wave in the sand for evaluation of the impulse capacity of the second wall; the scaled parameters required are given in the program output.

Subroutine SSTIFF. This subroutine reads in the slab material properties, thickness, areas of reinforcing steel, slab support conditions, and allowable rotation capacity. Using the general procedures given in

Reference 3, the subroutine determines the moment capacity, section properties, shear strength, location of yield line, resistance of the slab, maximum allowable deflection, and stiffness. Seven support condition options are considered for a slab.

1. Bottom side fixed, three sides free
2. Two adjacent sides fixed, two sides free
3. Three sides (two vertical and bottom horizontal) fixed, one side free
4. Four sides fixed
5. Two horizontal sides fixed, two vertical sides free
6. Two horizontal sides simple support, two vertical sides free
7. One horizontal side fixed, opposite horizontal side simple, two vertical sides free.

These combinations can be used to represent side walls, backwalls, roofs and beams found in typical construction.

Subroutine PIC. Subroutine PIC was developed by Picatinny Arsenal [4] to determine the blast impulse on slabs. The program was modified by the Naval Surface Weapons Center, White Oak Laboratory [5] to facilitate geometry conditions and running time. The program incorporates experimental pressure and impulse data which it uses to calculate the impulse on a grid covering the slab. The program determines the reflections from sidewalls, floor, and roof and uses this data to determine the total average reflected impulse on the slab.

Subroutine SGRID. This subroutine determines the impulse reflected from the wall for each grid point on the blast wall.

Subroutine HBA. This subroutine determines the scaled height of the Mach stem triple point at a given scaled distance from a charge at a specified scaled height above the ground.

Subroutine RATIO. This subroutine calculates the length/height ratio for the blast wall, the charge-weight/wall-height ratio, and several other ratios needed in Subroutine PIC. The subroutine restricts these ratios to lie within certain limits representing the range of validity for the procedure.

Subroutine GRID. This subroutine determines the number of grid points on the blast wall at which values of the reflected impulse are to be calculated. A minimum of 5 x 5 and a maximum of 21 x 21 grid points can be chosen. The routine chooses the minimum odd number of grid points along the length and along the height of the blast wall which will assure that the projection of the charge center in the blast wall falls within 0.2 foot from both a horizontal and a vertical line of grid points.

Subroutine INTERP. This subroutine performs linear and logarithmic interpretation among a set of points representing a planar curve; the values representing the abscissa can be in either ascending or descending order. The routine is used to interpolate between TNT data points.

Subroutine EQUIV. This subroutine computes the equivalent spherical weight of TNT, taking into account the type of explosive, the shape and the projectile case. The routine uses subroutines HEDATA, ARDC, SHOCK and TNT.

Subroutine HEDATA. This subroutine contains tables of explosive components.

Subroutine ARDC. This subroutine computes standard atmospheric pressure and temperature for a given altitude.

Subroutine SHOCK. This subroutine calculates shape and case equivalency factors and the incident and reflected overpressure at a given distance.

Subroutine TNT. This routine contains data for a 1-lb TNT free air explosion.

Program Input

The program input consists of five cards per case. Additional cases may be stacked together. A blank card is used after the last case.

The users guide contained in the program is given here to assist in understanding the input.

CARD 1

FROM	TO	
COL 2	COL 70	HEADING
COL 71	COL 80	FLAG EQ O FOR PRESSURE CALCULATION EQ 1. FOR INPUT PRESSURE

CARD 2

COL 1	COL 10	WEIGHT OF ACTUAL EXPLOSIVE LB
COL 11	COL 20	EXPLOSIVE NUMBER SEE TABLE 2
COL 21	COL 30	EXPLOSIVE LENGTH/DIAMETER RATIO
COL 31	COL 40	PROJECTILE CASE WEIGHT/EXPLOSIVE WEIGHT RATIO
COL 41	COL 50	AMBIENT PRESSURE PSIA (DEFAULT 14.69 PSI)
COL 51	COL 60	AMBIENT TEMPERATURE ^{o}C (DEFAULT 20^{o})
COL 61	COL 70	ALTITUDE KFT (WHEN PRESSURE AND TEMPERATURE NOT SPECIFIED)

CARD 3

COL 1	COL 10	RA DISTANCE CHARGE TO WALL FT or EQUAL IMPULSE PSI-MS IF FLAG=1.0
COL 11	COL 20	H WALL HEIGHT FT
COL 21	COL 30	EL WALL LENGTH FT
COL 31	COL 40	HLIT HEIGHT CHARGE FT OR EQUAL PRESSURE PSI IF FLAG=1.0
COL 41	COL 50	ELLIT DISTANCE CHARGE TO LEFT SIDE WALL FT OR EQUAL DURATIN MS IF FLAG=1.0
COL 51	COL 60	TSAND SAND THICKNESS FT
COL 71		EQ1 FOR FLOOR REFLECTION
COL 72		EQ1 FOR ROOF REFLECTION
COL 73		EQ1 FOR LEFT WALL REFLECTION
COL 74		EQ1 FOR RIGHT WALL REFLECTION OTHERWISE EQ 0

CARD 4

COL 1	COL 10	FC DYNAMIC CONCRETE STRESS PSL
COL 11	COL 20	FY DYNAMIC STEEL STRESS PSL
COL 21	COL 30	TC THICKNESS CONCRETE IN.
COL 31	COL 40	THETA ALLOWABLE ROTATION DEGREES
COL 41	COL 42	NSIDE NUMBER OF SIDES WALL FIXED 1.0 BOTTOM SIDE FIXED 2.0 BOTTOM AND SIDE FIXED 3.0 2 SIDES AND BOTTOM FIXED 4.0 4 SIDES FIXED 5.0 SIMPLE SUPPORTED BEAM FIXED AT TOP AND BOTTOM 6.0 FIXED BEAM AT TOP AND BOTTOM 7.0 BEAM BOTTOM FIXED TOP SIMPLE

CARD 5

COL 1	COL 10	ASVT AREA VERTICAL STEEL BLAST SIDE/FT
COL 11	COL 20	ASVB AREA VERTICAL STEEL OPPOSITE SIDE/FT
COL 21	COL 30	ASHT AREA HORIZONTAL STEEL BLAST SIDE/FT
COL 31	COL 40	ASHB AREA HORIZONTAL STEEL OPPOSITE SIDE/FT
COL 41	COL 50	DVT DEPTH TO VERTICAL STEEL BLAST SIDE IN.
COL 51	COL 60	DVB DEPTH TO VERTICAL STEEL OPPOSITE SIDE IN.
COL 61	COL 70	DHT DEPTH TO HORIZONTAL STEEL BLAST SIDE IN.
COL 71	COL 80	DHB DEPTH TO HORIZONTAL STEEL OPPOSITE SIDE IN. DEPTH FROM OUTER CONCRETE SURFACE TO CENTER OF BAR

NOTE: All values fixed point except reflection code.

The explosive number refers to the list of explosives in Table 1. This is used to compute explosive equivalence. The length/diameter ratio for an explosive sphere is 0.0 which gives a shape factor of 1.0. For an uncased explosive the case explosive weight ratio is 0. For sea level calculations the ambient air pressure P_{amb} and temperature T_{amb} and altitude may be left blank and will default to 14.69 psi and 20°C. If the flag in the heading card is set to 1, the impulse, duration, and pressure are read on card 3. If the flag is left blank, the charge-wall distance, R height, and distance from the left side are read. If NSIDE is left blank, the program sums the number of reflecting sidewall surfaces specified on card 3. The separate use of NSIDE side is useful when a frangible wall is present, which creates a shock reflection but does not provide any support.

Figure 1 is a data input form which may be used to simplify the preparation of data.

Example Problems

The first example is a sidewall of a blast cell with a roof. The concrete wall is 32 feet long, 12 feet high, 2 feet thick with 4 feet of sand in composite action. Note that half the input thickness of the sand will be used by the program as added mass to the wall. The wall is restrained at the floor, roof, and left side; the right side is free. Since the three-side-fixed option condition assumes the sides and the bottom to be fixed, the wall must be reoriented when filling out the input form (Figure 2). Thus a height of 32 feet and length of 12 feet is used to properly orient the free edge. An allowable support rotation of 12 degrees is used which assumes lacing reinforcement will be used.

Figure 3 gives the results of the analysis. The blast impulse of 2,230 psi-ms was determined. The section properties are given. The shear exceeds the allowable, and lacing must be provided for the difference. The yield-line location is given. An ultimate resistance of 101.9 psi and a stiffness of 896 psi were determined. The impulse capacity of the wall is 4,135 psi-ms, which is much greater than the loading of 2,230 psi-ms, indicating the design is conservative. If a second wall of the same construction were present and acted with the first in composite construction, Figures 6-38 and 6-39 of Reference 3 could be used to determine its impulse capacity and the total capacity of both walls, using the scaled values of impulse, sand, and concrete thicknesses.

Figure 4 gives the input data of a second example for a roof of a blast cell 32 by 15 feet. The 32-foot side is used as the height to agree with the fixity condition. Figure 5 presents the computer analysis. In this case sand fill is not present and the wall response is calculated.

A maximum deflection of 19.27 inches was determined and may be compared with the allowable 12-degree-rotation deflection of 18.6 inches. In this case, the maximum deflection exceeds the 12-degree-rotation deflection, and collapse of the wall is indicated. The average and maximum scale velocity are given. The appendix gives two additional examples, comparing hand calculations with computer results.

Table 1. List of Explosives

Explosive Number	Explosive Name and Composition
1	TNT
2	TNETB
3	EXPLOSIVE D
4	PENTOLITE (PETN/TNT 50/50)
5	PICRATOL (EXPLOSIVE D/TNT 52/48)
6	CYCLOTOL (RDX/TNT 70/30)
7	COMP B (RDX/TNT/WAX 59.4/39.6/1.0)
8	RDX/WAX (98/2)
9	COMP A-3 (RDX/WAX 91/9)
10	TNETB/AL (90/10)
11	TNETB/AL (78/22)
12	TNETB/AL (72/28)
13	TNETB/AL (65/34)
14	TRITONAL (TNT/AL80/70)
15	RDX/AL/WAX (88/10/2)
16	RDX/AL/WAX (89/20/2)
17	RDX/AL/WAX (74/21/5)
18	RDX/AL/WAX (74/22/4)
19	RDX/AL/WAX (62/33/5)
20	TORPEX II (RDX/TNT/AL 42/40/18)
21	H6 (RDX/TNT/AL/WAX 45/29/21/5)
22	HBX-1 (RDX/TNT/AL/WAX 40/38/16/5)
23	HBX-3 (RDX/TNT/AL/WAX 31/29/35/5)
24	TNETB/RDX/AL 39/26/35
25	ALUMINUM
26	WAX
27	RDX
28	PETN
29	TETRYL

DISCUSSION

In general, the methods used in the computer program follow Reference 3 and, as such, the accuracy of both is the same. The solution of the dynamic response equation of motion has been found to agree very closely with the response chart of Reference 3. Additionally, the solution covers a wider range and, thus, is more accurate in the areas not defined by the response chart. When the loading is less than one hundredth of the natural period, the response is determined by impulse equilibrium. The basic dynamic model is limited to one mode of response and does not consider higher modes.

The ultimate moment capacity M_u of the slab is based on Equation 5-4 of Reference 3, as follows:

$$M_u = \frac{(A_s - A'_s) f_s}{b} (d - \frac{a}{2}) + \frac{A'_s f_s}{b} (d - d')$$

where

A'_s = area of compression reinforcement

A_s = area of tension reinforcement

b = width

a = depth of equivalent rectangular stress block

f_s = design steel stress

d = distance from extreme compression fiber to centroid of tension reinforcement

d' = distance from extreme compression fiber centroid to compression fiber

This equation for equal reinforcement in tension and compression reduces to

$$M_u = \frac{A'_s f_s}{b} (d - d')$$

The action of the concrete in compression is neglected since crushing at high rotations is assumed to occur. This results in disengagement of the concrete cover. When support rotations are restricted by lack of lacing, this equation becomes conservative. However, the more conventional concrete analysis procedures were not included to conform with the methodology given in Reference 3.

The blast impulse computation is restricted to a geometry in which the slab height-to-length ratio is greater than 0.2. The modification made by the Naval Surface Weapons Center to the original Picatinny Arsenal Program did not affect the results significantly for most

cases. However, it did remove several minor problem areas, such as the location of the charge. The blast impulse has all the limitations associated with the original programs which are caused by limitations in the test data. It assumes the charge is an equivalent sphere of TNT. Shape effects, explosive equivalence, and explosive casing are considered, but only in an empirical manner as a result of limited available data.

The cost of using the program on a CDC 7600 computer is about $2 per case compared with about 30 man-hours of hand computation. Further, the program allows for optimization of the cell properties resulting in less expensive construction.

ACKNOWLEDGMENTS

Mr. J. Proctor, Chief Explosive Effects Branch, Naval Sea Systems Center, White Oak Laboratory, Silver Springs, Maryland, provided a blast-effects computer program used in the development of this program. Mr. Norval Dobbs, Ammann and Whitney, Consulting Engineers provided the original blast impulse program. Their assistance is appreciated.

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3. Departments of the Army, Navy, and Air Force. TM5-1300, NAVFAC P-397, and AFM 88-22: Structures to resist the effects of accidental explosions. Washington, DC, Jun 1969.

4. Picatinny Arsenal. Technical Report 4070. An improved computer program to calculate the average blast impulse loads acting in a wall of a cubicle, by Stuart Levy; Dover, NJ, May 1970.

5. Personal Communication with J. Proctor, Naval Surface Weapons Laboratory, White Oak, MD, Jul 1, 1975.

Building ______________________ Date ________ Page ________

Format For Computer Program

Card	1 — 10	11 — 20	21 — 30	31 — 40	41 — 50	51 — 60	61 — 70	71	72	73	74	80
1	Heading							Flag 0 or 1 *				
2	W lb	Explo number	l/d ratio	case/explo	P amb psia	T amb ^{o} C	Altitude kft					
3	R_a ft/i psi ms*	H ft	L ft	h ft/PO psi *	ℓ ft/t_o ms *	t sand		F	R	L	R	
4	F_{dc} psi	F_{dy} psi	T_c in.	Theta O	N side							
5	A_sVT in.^{2}/ft	A_sVB in.^{2}/ft	A_sHT in.^{2}/ft	A_sHB in.^{2}/ft	D'VT in.	D'VB in.	D'HT in.	D'HB in.				

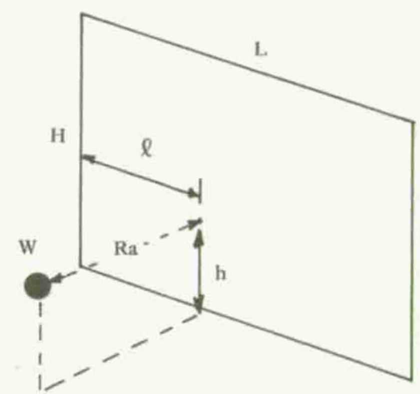


Figure 1. Data Input Form.

Building ______________________ Date ________ Page ________

Card — Format For Computer Program

Card												
1	Heading	TEST CASE EXAMPLE 1						Flag * (0) or 1				
2	1 10	11 20	21 30	31 40	41 50	51 60	61 70	71	72	73	74	80
	W lb	Explo number	l/d ratio	case/explo	P amb psia	T amb °C	Altitude kft					
	310.	1.	0.									
3	R_a ft/i psi ms *	H ft	L ft	h ft/PO psi *	ℓ ft/t_o ms *	t sand		F	R	L	R	
	5.	32.	12.	12.	3	4.		1	0	1	1	
4	F_{dc} psi	F_{dy} psi	T_c in.	Theta O	N side							
	5000.	48000.	24.	12.	3							
5	A_sVT in.^{2}/ft	A_sVB in.^{2}/ft	A_sHT in.^{2}/ft	A_sHB in.^{2}/ft	D'VT in.	D'VB in.	D'HT in.	D'HB in.				
	1.58	1.58	1.58	1.58	3.	3.	3.	3.				

Figure 2. Example Problem 1.

Figure 3. Computer Results Example 1.

```
 T E S T   C A S E   E X A M P L E  1
TNT
EXPLOSIVE PROPERTIES.....CHARGE WEIGHT(LB) =  310.0



NUMBER EQWT    EFORM EXPLOSIVE COMPOSITION BY WEIGHT
             KCAL/G      C      H      N      O     AL
   1  1.000 -.078400  .370  .022  .185  .423 0.000
PAMB(PSIA)=  14.69        TAMB(C)=  20.00
.....CASE WEIGHT CORRECTION IS CRUDE.  PSI EXCEEDS  RANGE OF EXPERIMENTAL DATA.

SHOCK WAVE CALCULATION
INPUT PARAMETERS                             CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)        =   310.0           ADJUSTED WT(LB TNT)   =   310.0
EXPLOSIVE NUMBER         =     1             HE ENERGY FACTOR      =   1.000
L/D RATIO                = -0.               CHARGE SHAPE FACTOR   =   1.000
CASE/CHARGE WT RATIO     = -0.               CASE WEIGHT FACTOR    =   1.000
CHAMBER PRESSURE(PSIA)=    14.69             PRESSURE SCALE FACTOR=   1.000
CHAMBER TEMP(C)          =   20.00           DISTANCE SCALE FACTOR=   .1477
ALTITUDE (KFT)           = -0.               TIME SCALE FACTOR     =   .1490
                                             NORMAL REFL FACTOR    =   10.47
DESIRED DISTANCE(FT)    =   3.000
                (CM)    =   91.44
 TIME AFTER  TIME AFTER   INCIDENT    NORM REFL
 EXPLOSION   SHOCK ARR   OVERPRESS   OVERPRESS
  (MSEC)      (MSEC)       (PSI)       (PSI)
   .1156      0.            2736      28.6323E+03
   .2442       .1287        862.9        9031
   .3086       .1930        543.7        5690
   .3729       .2573        353.0        3695
   .4372       .3216        230.9        2417
   .5015       .3860        148.8        1558
   .5659       .4503        91.67       959.4
   .6302       .5146        50.95       533.2
   .6945       .5789        21.48       224.9
   .7588       .6433       0.          0.
IMPULSE (PSI.MSEC)--
    INCIDENT =   351.9
    REFLECTED=    3683
.....CAUTION--CONTACT SURFACE HAS ARRIVED.
       DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL= 12.3181E-03


                                                   INPUT


        DISTANCE OF CHARGE FROM BLAST WALL          FT.              3.00

        CHARGE WEIGHT                               LBS.           310.00

        BLAST WALL HEIGHT                           FT.             32.00

        BLAST WALL LENGTH                           FT.             12.00

        HEIGHT OF CHARGE ABOVE GROUND               FT.             17.00

        MIN. DIST. BETWEEN CHARGE + ADJ. WALL       FT.              3.00

        REFLECTION CODE                                       1   0   1   1

        TOTAL  IMPULSE          2230.95 PSI-MS

        DURATION OF LOAD         7.64583  MSEC

        FICTITIOUS PEAK PRESSURE       583.57205  PSI




    DYNAMIC CONCRETE STRENGTH        5000.00
    DYNAMIC STEEL STRESS            48000.00
    THICKNESS CONCRETE   INCHES       24.0000
    THICKNESS OF SAND    INCHES       48.0000
    THETA ALLOWABLE     DEGREES       12.0000
```

```
AREA VERT TOP STEEL/FT          1.5800  COVER    2.0000
AREA VERT BOT STEEL/FT          1.5800  COVER    2.0000
AREA HORIZ TOP STEEL/FT         1.5800  COVER    3.0000
AREA HORIZ BOT STEEL/FT         1.5800  COVER    3.0000

CONCRETE MODULUS PSI                4030509
RATIO MOD STEEL/CONCRETE          7.20
GROSS MOMENT INERTIA           1152.00
AVE CRACKED MOM INERTIA         304.95
AVE MOMENT INERTIA              728.47
AVERAGE PERCENT STEEL           .0061
D FACTOR MU=1/6                         3020078962
D FACTOR  MU= 0.3                      3226506337


ALLOW SHEAR UNREINFORCED WEB     115.16  PSI          2475.99 LBS/IN WIDTH
ALLOW SHEAR AT SUPPORT           720.00  PSI         15480.00  LBS/IN WIDTH
UNREINFORCED CONCRETE  THETA LE 2 DEG

POSITIVE VERTICAL MOMENT   126400.00
NEGATIVE VERTICAL MOMENT   126400.00
POSITIVE HORIZONTAL MOMENT   113760.00
NEGATIVE HORIZONTAL MOMENT   113760.00


SUPPORT ON  3 SIDES

YIELD LINE  Y  ABOVE FLOOR

LOCATION YIELD LINE LENGTH        72.00
LOCATION YIELD LINE HEIGHT       111.37
ULTIMATE LOAD CAPACITY  RU   101.9133
HORIZ SHEAR LOAD AT SUPPORT         6592.36  LB/IN WIDTH
VERT SHEAR LOAD AT SUPPORT          6809.89  LB/IN WIDTH
HORIZ SHEAR AT DIST FROM SUPPORT     217.36  PSI
VERT SHEARAT DIST FROM SUPPORT       243.92  PSI
ALLOWABLE MAX DEFLECTION      14.8890



LOAD MASS FACTOR                 .6270
MASS CONCRETE ONLY             3381.04



FIRST YIELD POINT AT PT2
ELASTIC  LIMIT  RE PSI            65.66
ELASTIC DEFLECTION  XE           .0646

SECOND YIELD AT PT 1
ELASTO PLASTIC LIMIT            76.66
ELASTO-PLASTIC DEFLECTION        .0868
ULTIMATE RESISTANCE            101.91
PLASTIC DEFLECTION               .1379



ULTIMATE RESISTANCE RU       101.91
ELASTIC DEFLECTION LIMIT  XE      .1137
STIFFNESS  KE                   896.51


NATURAL PERIOD              15.751966
IMPULSE CAPACITY ONE WALL      4135.19
SCALLED IMPULSE CAPACITY        612.17
SCALED SAND THICKNESS           .5922
SCALED CONCRETE THICKNESS        .2961
```

Building ____________________ Date ________ Page ________

Card | Format For Computer Program

Card	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71	72	73	74	80
1	Heading	EXAMPLE 2						Flag * (0) or 1				
2	W lb	Explo number	l/d ratio	case/explo	P amb psia	T amb °C	Altitude kft					
	650.	1.	0									
3	R_a ft/i psi ms*	H ft	L ft	h ft/PO psi*	ℓ ft/t_o ms*	t sand		F	R	L	R	
	8.	32.	15	16.	7.50	0		1	0	1	1	
4	F_{dc} psi	F_{dy} psi	T_c in.	Theta O	N side							
	5000.	48000.	24.	12.	3.							
5	A_sVT in.^{2}/ft	A_sVB in.^{2}/ft	A_sHT in.^{2}/ft	A_sHB in.^{2}/ft	D'VT in.	D'VB in.	D'HT in.	D'HB in.				
	1.58	1.58	1.58	1.58	2.	2.	3	3.				

Figure 4. Example Problem 2.

Figure 5. Computer Results Example 2.

```
 T E S T  C A S E   E X A M P L E  2
INI
EXPLOSIVE PROPERTIES.....CHARGE WEIGHT(LB) =  650.0
NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G      C      H      N      O     AL
  1  1.000 -.078400  .370  .022  .185  .423 0.000
PAMB(PSIA)=  14.69         TAMB(C)=  20.00
.....CASE WEIGHT CORRECTION IS CRUDE.  PSI EXCEEDS  RANGE OF EXPERIMENTAL DATA.

SHOCK WAVE CALCULATION
INPUT PARAMETERS                                CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)          =   650.0            ADJUSTED WT(LB TNT)  =    650.0
EXPLOSIVE NUMBER           =     1              HE ENERGY FACTOR     =    1.000
L/D RATIO                  = -0.                CHARGE SHAPE FACTOR  =    1.000
CASE/CHARGE WT RATIO       = -0.                CASE WEIGHT FACTOR   =    1.000
CHAMBER PRESSURE(PSIA)=       14.69             PRESSURE SCALE FACTOR=    1.000
CHAMBER TEMP(C)            =   20.00            DISTANCE SCALE FACTOR=    .1154
ALTITUDE (KFT)             = -0.                TIME SCALE FACTOR    =    .1164
                                                NORMAL REFL FACTOR   =    8.726
DESIRED DISTANCE(FT)    =    8.000
                (CM)    =    243.8
 TIME AFTER   TIME AFTER    INCIDENT     NORM REFL
 EXPLOSION    SHOCK ARR     OVERPRESS    OVERPRESS
  (MSEC)       (MSEC)        (PSI)        (PSI)
   .5229       0.            997.0         8699
   .8257        .3028        314.5         2744
   .9770        .4541        198.1         1729
  1.128         .6055        126.7         1123
  1.280         .7569        84.16        734.4
  1.431         .9083        54.24        473.2
  1.583        1.060         33.41        291.5
  1.734        1.211         18.57        162.0
  1.885        1.362         7.830        68.32
  2.037        1.514         0.           0.
IMPULSE (PSI.MSEC)--
    INCIDENT =    301.8
    REFLECTED=    2633
.....CAUTION--CONTACT SURFACE HAS ARRIVED.
       DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL= 94.0671E-03
```

INPUT

2.037 1.514 0. 0.

IMPULSE (PSI.MSEC)--
INCIDENT = 301.8
REFLECTED= 2633

.....CAUTION--CONTACT SURFACE HAS ARRIVED.
DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL= 94.0671E-03

INPUT

DISTANCE OF CHARGE FROM BLAST WALL	FT.	8.00
CHARGE WEIGHT	LBS.	650.00
BLAST WALL HEIGHT	FT.	32.00
BLAST WALL LENGTH	FT.	15.00
HEIGHT OF CHARGE ABOVE GROUND	FT.	16.00
MIN. DIST. BETWEEN CHARGE + ADJ. WALL	FT.	7.50
REFLECTION CODE		1 0 1 1

TOTAL IMPULSE 2992.05 PSI-MS

DURATION OF LOAD 5.01601 MSEC

FICTITIOUS PEAK PRESSURE 1192.99700 PSI

2

DYNAMIC CONCRETE STRENGTH	5000.00		
DYNAMIC STEEL STRESS	48000.00		
THICKNESS CONCRETE INCHES	24.0000		
THICKNESS OF SAND INCHES	0.0000		
THETA ALLOWABLE DEGREES	12.0000		

AREA VERT TOP STEEL/FT	1.5800	COVER	2.0000
AREA VERT BOT STEEL/FT	1.5800	COVER	2.0000
AREA HORIZ TOP STEEL/FT	1.5800	COVER	3.0000
AREA HORIZ BOT STEEL/FT	1.5800	COVER	3.0000

CONCRETE MODULUS PSI 4030509

RATIO MOD STEEL/CONCRETE	7.20
GROSS MOMENT INERTIA	1152.00
AVE CRACKED MOM INERTIA	304.95
AVE MOMENT INERTIA	728.47
AVERAGE PERCENT STEEL	.0061
D FACTOR MU=1/6	3020078962
D FACTOR MU= 0.3	3226506337

ALLOW SHEAR UNREINFORCED WEB	115.16	PSI	2475.99	LBS/IN WIDTH
ALLOW SHEAR AT SUPPORT	720.00	PSI	15480.00	LBS/IN WIDTH

UNREINFORCED CONCRETE THETA LE 2 DEG

POSITIVE VERTICAL MOMENT	126400.00
NEGATIVE VERTICAL MOMENT	126400.00
POSITIVE HORIZONTAL MOMENT	113760.00
NEGATIVE HORIZONTAL MOMENT	113760.00

SUPPORT ON 3 SIDES

YIELD LINE Y ABOVE FLOOR

LOCATION YIELD LINE LENGTH	90.00	
LOCATION YIELD LINE HEIGHT	137.89	
ULTIMATE LOAD CAPACITY RU	66.4754	
HORIZ SHEAR LOAD AT SUPPORT	5221.07	LB/IN WIDTH
VERT SHEAR LOAD AT SUPPORT	5499.91	LB/IN WIDTH
HORIZ SHEAR AT DIST FROM SUPPORT	186.51	PSI
VERT SHEARAT DIST FROM SUPPORT	208.23	PSI
ALLOWABLE MAX DEFLECTION	18.6112	

ALLOWABLE MAX DEFLECTION 18.6112

```
VERT SHEAR LOAD AT SUPPORT                 5499.91  LB/IN WIDTH
HORIZ SHEAR AT DIST FROM SUPPORT            186.51  PSI
VERT SHEARAT DIST FROM SUPPORT              208.23  PSI
ALLOWABLE MAX DEFLECTION          18.6112

LOAD MASS FACTOR                   .6168
MASS CONCRETE ONLY               3325.85

FIRST YIELD POINT AT PT2
ELASTIC  LIMIT  RE PSI             41.90
ELASTIC DEFLECTION  XE             .0873

SECOND YIELD AT PT 1
ELASTO PLASTIC LIMIT               50.67
ELASTO-PLASTIC DEFLECTION          .1295
ULTIMATE RESISTANCE                66.48
PLASTIC DEFLECTION                 .2065

ULTIMATE RESISTANCE RU            66.48
ELASTIC DEFLECTION LIMIT  XE       .1635
STIFFNESS  KE                     406.58
```

2

MASS	3325.855
LOAD	1192.997
DURATION	5.016
RESISTANCE	66.475
STIFFNESS	406.578

TIME	ACCELERATION	VELOCITY	DISPLACEMENT	LOAD	RESISTANCE
.501601	.3175	.1700	.0435	1073.6973	17.6895
1.003203	.2670	.3129	.2854	954.3976	66.4754
1.504804	.2311	.4379	.4744	835.0979	66.4754
2.006406	.1952	.5448	.7216	715.7982	66.4754
2.508007	.1594	.6337	1.0180	596.4985	66.4754
3.009609	.1235	.7047	1.3544	477.1988	66.4754
3.511210	.0876	.7576	1.7219	357.8991	66.4754
4.012812	.0518	.7926	2.1114	238.5994	66.4754
4.514413	.0159	.8095	2.5140	119.2997	66.4754
5.016015	-.0200	.8085	2.9205	.0000	66.4754
5.517616	-.0200	.7985	3.3236	0.0000	66.4754
6.019218	-.0200	.7885	3.7216	0.0000	66.4754
6.520819	-.0200	.7784	4.1145	0.0000	66.4754
7.022421	-.0200	.7684	4.5025	0.0000	66.4754
7.524022	-.0200	.7584	4.8854	0.0000	66.4754
8.025624	-.0200	.7483	5.2633	0.0000	66.4754
8.527225	-.0200	.7383	5.6361	0.0000	66.4754
9.028827	-.0200	.7283	6.0040	0.0000	66.4754
9.530428	-.0200	.7183	6.3668	0.0000	66.4754
10.032029	-.0200	.7082	6.7245	0.0000	66.4754
10.533631	-.0200	.6982	7.0773	0.0000	66.4754
11.035232	-.0200	.6882	7.4250	0.0000	66.4754
11.536834	-.0200	.6782	7.7677	0.0000	66.4754
12.038435	-.0200	.6681	8.1053	0.0000	66.4754
12.540037	-.0200	.6581	8.4380	0.0000	66.4754
13.041638	-.0200	.6481	8.7656	0.0000	66.4754
13.543240	-.0200	.6381	9.0881	0.0000	66.4754
14.044841	-.0200	.6280	9.4057	0.0000	66.4754
14.546443	-.0200	.6180	9.7182	0.0000	66.4754
15.048044	-.0200	.6080	10.0257	0.0000	66.4754
15.549646	-.0200	.5980	10.3281	0.0000	66.4754
16.051247	-.0200	.5879	10.6255	0.0000	66.4754
16[illegible]28[illegible]	[illegible]	[illegible]9	[illegible]91[illegible]	[illegible]00	6[illegible]754
17.054450	-.0200	.5679	11.2053	0.0000	66.4754
17[illegible]60052	[illegible]02[illegible]	[illegible]9	[illegible]48[illegible]	[illegible]00	6[illegible]754
18.057653	-.0200	.5478	11.7649	0.0000	66.4754
18.559255	-.0200	.5378	12.0372	0.0000	66.4754
19.060856	-.0200	.5278	12.3045	0.0000	66.4754
19.562457	-.0200	.5178	12.5667	0.0000	66.4754
20.064059	-.0200	.5077	12.8239	0.0000	66.4754
20.565660	-.0200	.4977	13.0761	0.0000	66.4754
21.067262	-.0200	.4877	13.3232	0.0000	66.4754
21.568863	-.0200	.4777	13.5653	0.0000	66.4754
22.070465	-.0200	.4676	13.8024	0.0000	66.4754
22.572066	-.0200	.4576	14.0344	0.0000	66.4754
23.073668	-.0200	.4476	14.2614	0.0000	66.4754
23.575269	-.0200	.4375	14.4834	0.0000	66.4754
24.076871	-.0200	.4275	14.7004	0.0000	66.4754
24.578472	-.0200	.4175	14.9123	0.0000	66.4754
25.080074	-.0200	.4075	15.1192	0.0000	66.4754
25.581675	-.0200	.3974	15.3211	0.0000	66.4754
26.083277	-.0200	.3874	15.5179	0.0000	66.4754
26.584878	-.0200	.3774	15.7098	0.0000	66.4754
27.086480	-.0200	.3674	15.8966	0.0000	66.4754
27.588081	-.0200	.3573	16.0783	0.0000	66.4754
28.089683	-.0200	.3473	16.2550	0.0000	66.4754
28.591284	-.0200	.3373	16.4267	0.0000	66.4754
29.092885	-.0200	.3273	16.5934	0.0000	66.4754
29.594487	-.0200	.3172	16.7551	0.0000	66.4754
30.096088	-.0200	.3072	16.9117	0.0000	66.4754
30.597690	-.0200	.2972	17.0633	0.0000	66.4754
31.099291	-.0200	.2872	17.2098	0.0000	66.4754
31.600893	-.0200	.2771	17.3513	0.0000	66.4754
32.102494	-.0200	.2671	17.4878	0.0000	66.4754
32.604096	-.0200	.2571	17.6193	0.0000	66.4754
33.105697	-.0200	.2471	17.7457	0.0000	66.4754
33.607299	-.0200	.2370	17.8672	0.0000	66.4754
34.108900	-.0200	.2270	17.9835	0.0000	66.4754
34.610502	-.0200	.2170	18.0949	0.0000	66.4754
35.112103	-.0200	.2070	18.2012	0.0000	66.4754
35.613705	-.0200	.1969	18.3025	0.0000	66.4754
36.115306	-.0200	.1869	18.3988	0.0000	66.4754
36.616908	-.0200	.1769	18.4900	0.0000	66.4754
37.118509	-.0200	.1669	18.5762	0.0000	66.4754
37.620111	-.0200	.1568	18.6574	0.0000	66.4754
38.121712	-.0200	.1468	18.7336	0.0000	66.4754
38.623313	-.0200	.1368	18.8047	0.0000	66.4754
39.124915	-.0200	.1268	18.8708	0.0000	66.4754
39.626516	-.0200	.1167	18.9318	0.0000	66.4754
40.128118	-.0200	.1067	18.9879	0.0000	66.4754
40.629719	-.0200	.0967	19.0389	0.0000	66.4754
41.131321	-.0200	.0866	19.0849	0.0000	66.4754
41.632922	-.0200	.0766	19.1258	0.0000	66.4754
42.134524	-.0200	.0666	19.1617	0.0000	66.4754
42.636125	-.0200	.0566	19.1926	0.0000	66.4754
43.137727	-.0200	.0465	19.2185	0.0000	66.4754
43.639328	-.0200	.0365	19.2393	0.0000	66.4754
44.140930	-.0200	.0265	19.2551	0.0000	66.4754
44.642531	-.0200	.0165	19.2659	0.0000	66.4754
45.144133	-.0200	.0064	19.2716	0.0000	66.4754
45.645734	-.0200	-.0036	19.2724	0.0000	66.4754
46.147336	-.0200	-.0136	19.2680	0.0000	66.4754

NATURAL PERIOD	17.970463
MAXIMUM DEFLECTION	19.272357
TIME TO MAXIMUM DEFLECTION	46.147336
DURATION/NATURAL PERIOD	.279126
LOAD/RESISTANCE	17.946438
ELASTIC DEFLECTION LIMIT	.163500
MAX FRAGMENT SPALL VELOCITY FT/SEC	67.460980

WALL COLLAPSES

AVERAGE SCAB VELOCITY	13.07
MAX SCAB VELOCITY	65.35

Appendix

TWO ADDITIONAL EXAMPLES AND CALCULATIONS

EXAMPLE 3. HAND CALCULATION [3]

Concrete Wall

Thickness concrete = 2 ft, 0 in.

Steel reinforcement = No. 5 at 10 in.

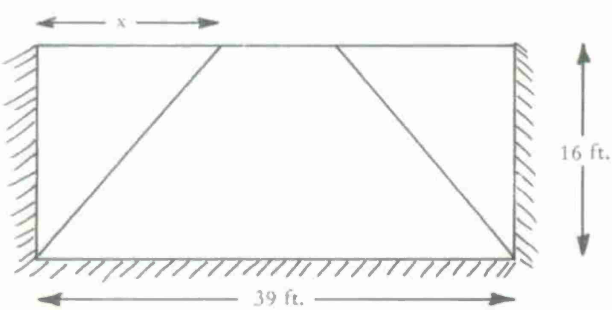
Assume concrete cover = 1-3/8 in.

Assume f_{cd} = 10,000 psi

Assume f_{yd} = 48,000 psi

Moment Capacity For Equal Reinforcement

$$M = f_s A_s (d-d') = 48{,}000\,(0.31/10)(22.62 - 1.37)$$
$$M = 1{,}488\,(21.25)$$
$$M = 31{,}620 \text{ in.-lb/in.}$$
$$d = 22.62$$
$$d' = 1.375$$



L/H = 39/16 = 2.68

x/L = 0.44

yield line = (0.44)(39 x 12) = 206 in.

Ultimate Resistance

$$r_u = \frac{5(M_{uV} + M_{uH})}{x^2} = \frac{31{,}620}{(206^2)} = 7.60 \text{ psi}$$

$$E_c = 57{,}000 \sqrt{10{,}000} = 5{,}700{,}000 \text{ psi}$$

$$n = \frac{29 \times 10^6}{5.7 \times 10^6} = 5.08$$

$$I_s = \frac{b\ T_c^{\ 3}}{12} = \frac{(1)(24)^3}{12} = 1{,}152 \text{ in.}^4\text{/in.}$$

$$A_s = 0.031\text{/in.}$$

$$P = 0.031/21.5 = 0.00144$$

$$F = 0.005$$

$$I_c = (0.006)(1)(21.5)^3 = 59.63 \text{ in.}^4\text{/in.}$$

$$I_a = 606 \text{ in.}^4\text{/in.}$$

First Yield Point

$$H/L = 16/39 = 0.41$$

$$\beta_1 = 0.07$$

$$\beta_2 = 0.35$$

$$\beta_3 = 0.28$$

$$\gamma_1 = 0.048$$

$$r_e = \frac{M}{\beta_2\ H^2} = \frac{31.620}{(0.35)(12 \times 16)^2} = 2.45 \text{ psi}$$

$$D = \frac{(5.7 \times 10^6)(600)}{(1)[1 - (1/6)^2]} = 3.5177 \times 10^9$$

$$x_e = \frac{0.048(2.45)(12 \times 16)^4}{3.517 \times 10^9} = 0.045 \text{ in.}$$

Second Yield Point

$$H/L = 0.41$$

$$\beta_1 = 0.117$$

$$\gamma_2 = 0.055$$

$$\beta_3 = 0.315$$

$$M_3 = \beta_3\ r_e\ H^2 = 0.28(2.45)(12 \times 16)^2 = 25{,}295$$

$$D = 3.77 \times 10^9$$

$$\Delta M_3 = 31{,}620 - 25{,}295 = 6{,}325$$

$$\Delta r_{ep} = \frac{6{,}325}{(0.315)(192)^2} = 0.545$$

$$r_{ep} = 0.545 + 2.45 = 2.99$$

$$\Delta_x = \frac{(0.055)(0.545)(112)^4}{3.77 \times 10^9} = 0.0106$$

$$x_{ep} = 0.0106 + 0.045 = 0.0556 \text{ in.}$$

Third Yield Point

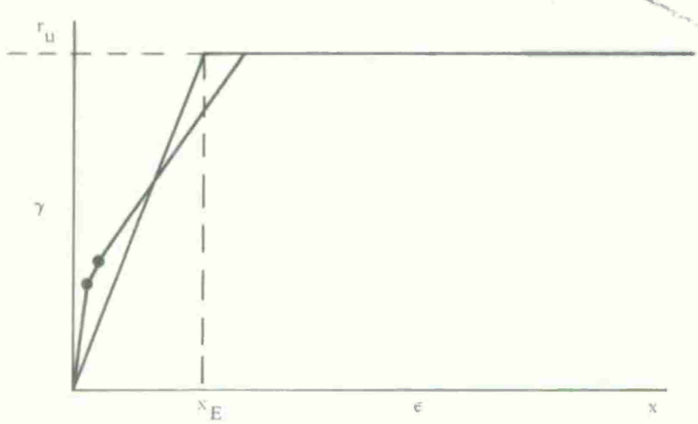
$$\gamma_1 = 0.2$$

$$\beta_1 = 0.27$$

$$\Delta_r = 7.60 - 2.99 = 4.61 \text{ psi}$$

$$\Delta_x = \frac{(0.2)(192)^4(4.61)}{3.77 \times 10^9} = 0.332$$

$$x_p = 0.0556 + 0.332 = 0.3876 \text{ in.}$$



$$x_E = x_e\left(\frac{r_{ep}}{r_u}\right) + x_{ep}\left(1 - \frac{r_e}{r_u}\right) + x_p\left(1 - \frac{r_{ep}}{r_u}\right)$$

$$= \left[0.068\left(\frac{4.49}{11.4}\right) + 0.084\left(1 - \frac{3.676}{11.4}\right) + 0.582\left(1 - \frac{4.49}{11.4}\right)\right]0.666$$

$$= 0.436 \times 0.666 = 0.290 \text{ in.}$$

$$k_E = 26.14 \text{ psi/in.}$$

$r_e = 7.60$

$x_E = 0.290$

$K_E = 26.1$

Shear Loads

$$V = \frac{3\ r_u\ x}{5} = \frac{3(7.6)(206)}{5} = 939\ \text{lb/in.}$$

Shear at Distance

$$V = \frac{3\ r_u\ [1 - (d/x)]^2}{(d/x)\ [5 - 4\ (d/x)]} = \frac{3(7.6)\ [1 - 22.6/20.6\ ]}{(27.6/20.6)\ [5 - 4\ (22.6/20.6)]}$$

$$= 40.6$$

$$v = 40.6 \times 24 = 973\ \text{lb}$$

Shear at Distance From Support

$$\frac{3\ r_u\ [1 - (d/x)]^2}{(d/x)[5 - 4(d/x)]} = \frac{3(7.6)[1 - (22.6/206)]^2}{(22.6/206)[5 - 4\ (27.6/206)]} = 36\ \text{psi}$$

$$f_{cd} = 10{,}000$$

$$f_c\ \text{static} = 8{,}000$$

$$V_c = 4(1.9\sqrt{f_c} + 2{,}500\ P) \leqslant 2.28\ 4\sqrt{f_c}$$

$$\cong 144$$

Mass

$$\text{Mass} = 0.53 \times 2(2696) = 2{,}850\ \text{psi-msec}^2/\text{in.}$$

Impulse Data

$R = 10$ ft

$H = 16$ ft

$e_h = 4$ ft

$W = 300$ lb

$L = 39$ ft

$l = 12$ ft

$N = 3$

From impulse charts,

$I = 1,190$ psi-msec

Equivalent pressure = 140 psi

duration = 17 msec

WALL RESPONSE

$M = 2,850$ lb-sec^2/in.

$r_u = 7.6$ psi

$k_E = 26$ psi

$P = 140$ psi

$T_D = 17$ msec

Natural period = 65.6 msec

Duration/natural period = 0.26

Load/resistance = 18.2

Response, from Reference 3, Chapter 6

Maximum deflection = 31.14 in.

Building ______________________ Date ________ Page ________

Card Format For Computer Program

Card												
1	Heading	TEST CASE EXAMPLE 3						Flag * 0 or 1				
2	1 10	11 20	21 30	31 40	41 50	51 60	61 70	71	72	73	74	80
	W lb	Explo number	l/d ratio	case/explo	P amb psia	T amb ^{o}C	Altitude kft					
	300	1.	0.									
3	R_a ft/i psi ms *	H ft	L ft	h ft/PO psi *	ℓ ft/t_o ms *	t sand		F	R	L	R	
	10.	16.	34.	4.	12.	0.		1	0	1	1	
4	F_{dc} psi	F_{dy} psi	T_c in.	Theta O	N side							
	10000.	48000	24.	2.	3.							
5	A_sVT in.^{2}/ft	A_sVB in.^{2}/ft	A_sHT in.^{2}/ft	A_sHB in.^{2}/ft	D'VT in.	D'VB in.	D'HT in.	D'HB in.				
	0.372	0.372	0.372	0.372	1.375	1.375	1.375	1.375				

Example 3. Computer Analysis.

```
TEST CASE EXAMPLE 3
INT
EXPLOSIVE PROPERTIES.....CHARGE WEIGHT(LB) =  300.0
NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G      C      H      N      O     AL
   1  1.000 -.078400  .370  .022  .185  .423 0.000
PAMB(PSIA)=  14.69        TAMB(C)=  20.00
.....CASE WEIGHT CORRECTION IS CRUDE.  PSI EXCEEDS  RANGE OF EXPERIMENTAL DATA.

SHOCK WAVE CALCULATION
INPUT PARAMETERS                              CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)        =   300.0            ADJUSTED WT(LB-TNT)  =   300.0
EXPLOSIVE NUMBER         =     1              HE ENERGY FACTOR     =   1.000
L/D RATIO                = -0.                CHARGE SHAPE FACTOR  =   1.000
CASE/CHARGE WT RATIO     = -0.                CASE WEIGHT FACTOR   =   1.000
CHAMBER PRESSURE(PSIA)=    14.69              PRESSURE SCALE FACTOR=   1.000
CHAMBER TEMP(C)          =   20.00            DISTANCE SCALE FACTOR=   .1494
ALTITUDE (KFT)           = -0.                TIME SCALE FACTOR    =   .1506
                                              NORMAL REFL FACTOR   =   7.185
DESIRED DISTANCE(FT)   =   10.00
                (CM)   =   304.8
 TIME AFTER  TIME AFTER   INCIDENT   NORM REFL
 EXPLOSION   SHOCK ARR    OVERPRESS  OVERPRESS
  (MSEC)      (MSEC)       (PSI)      (PSI)
   .9507      0.           408.0       2931
  1.311        .3601       128.7      924.5
  1.491        .5402       81.08      582.5
  1.671        .7202       52.65      378.3
  1.851        .9003       34.44      247.4
  2.031       1.080        22.19      159.5
  2.211       1.260        13.67      98.22
  2.391       1.440        7.597      54.59
  2.571       1.620        3.204      23.02
  2.751       1.801        0.         0.
IMPULSE (PSI.MSEC)--
    INCIDENT =   146.9
    REFLECTED=    1055
.....CAUTION--CONTACT SURFACE HAS ARRIVED.
      DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL=   .3147

                                        INPUT

     DISTANCE OF CHARGE FROM BLAST WALL         FT.             10.00

     CHARGE WEIGHT                              LBS.           300.00

     BLAST WALL HEIGHT                          FT.             16.00

     BLAST WALL LENGTH                          FT.             39.00

     HEIGHT OF CHARGE ABOVE GROUND              FT.              4.00

     MIN. DIST. BETWEEN CHARGE + ADJ. WALL      FT.             12.00

     REFLECTION CODE                                        1  0  1  1

     TOTAL  IMPULSE          1203.85 PSI-MS

     DURATION OF LOAD        17.08993  MSEC

     FICTITIOUS PEAK PRESSURE       140.88388  PSI

     DYNAMIC CONCRETE STRENGTH     10000.00
     DYNAMIC STEEL STRESS          48000.00
     THICKNESS CONCRETE  INCHES      24.0000
     THICKNESS OF SAND   INCHES       0.0000
     THETA ALLOWABLE     DEGREES      2.0000

     AREA VERT TOP STEEL/FT            .3720  COVER    1.3750
     AREA VERT BOT STEEL/FT            .3720  COVER    1.3750
     AREA HORIZ TOP STEEL/FT           .3720  COVER    1.3750
     AREA HORIZ BOT STEEL/FT           .3720  COVER    1.3750

     CONCRETE MODULUS PSI                  5700000
     RATIO MOD STEEL/CONCRETE             5.09
     GROSS MOMENT INERTIA              1152.00
     AVE CRACKED MOM INERTIA             69.24
     AVE MOMENT INERTIA                 610.62
     AVERAGE PERCENT STEEL              .0014
     D FACTOR MU=1/6                          3580072390
     D FACTOR  MU= 0.3                        3824776239

     ALLOW SHEAR UNREINFORCED WEB     147.36  PSI          3334.06 LBS/IN WIDTH
     ALLOW SHEAR AT SUPPORT          1440.00  PSI         32580.00  LBS/IN WIDTH
     UNREINFORCED CONCRETE   THETA LE 2 DEG

     POSITIVE VERTICAL MOMENT     31620.00
     NEGATIVE VERTICAL MOMENT     31620.00
     POSITIVE HORIZONTAL MOMENT     31620.00
     NEGATIVE HORIZONTAL MOMENT     31620.00


     SUPPORT ON  3 SIDES

     YIELD LINE  X  FROM SIDE

     LOCATION YIELD LINE LENGTH       204.60
     LOCATION YIELD LINE HEIGHT       192.00
     ULTIMATE LOAD CAPACITY  RU      7.5534
     HORIZ SHEAR LOAD AT SUPPORT            927.27  LB/IN WIDTH
     VERT SHEAR LOAD AT SUPPORT             955.47  LB/IN WIDTH
     HORIZ SHEAR AT DIST FROM SUPPORT        35.57  PSI
     VERT SHEARAT DIST FROM SUPPORT          36.80  PSI
     ALLOWABLE MAX DEFLECTION           6.7106

     LOAD MASS FACTOR                    .5260
     MASS CONCRETE ONLY                2836.07

     FIRST YIELD POINT AT PT2
     ELASTIC  LIMIT  RE PSI               2.28
     ELASTIC DEFLECTION  XE              .0435

     SECOND YIELD AT PT 3
     ELASTO PLASTIC LIMIT                2.83
     ELASTO-PLASTIC DEFLECTION           .0586
     ULTIMATE RESISTANCE                 7.55
     PLASTIC DEFLECTION                  .3907

     ULTIMATE RESISTANCE RU          7.55
     ELASTIC DEFLECTION LIMIT  XE       .3014
     STIFFNESS  KE                     25.06
```

MASS 2836.068
LOAD 140.884
DURATION 17.090
RESISTANCE 7.553
STIFFNESS 25.064

TIME	ACCELERATION	VELOCITY	DISPLACEMENT	LOAD	RESISTANCE
1.708993	.0441	.0803	.0700	126.7955	1.7538
3.417986	.0374	.1501	.2684	112.7071	6.7281
5.126979	.0321	.2092	.6095	98.6187	7.5534
6.835971	.0271	.2598	1.0115	84.5303	7.5534
8.544964	.0222	.3019	1.4927	70.4419	7.5534
10.253957	.0172	.3356	2.0387	56.3536	7.5534
11.962950	.0122	.3608	2.6349	42.2652	7.5534
13.671943	.0073	.3774	3.2669	28.1768	7.5534
15.380936	.0023	.3856	3.9201	14.0884	7.5534
17.089929	-.0027	.3853	4.5801	.0000	7.5534
18.798922	-.0027	.3808	5.2347	0.0000	7.5534
20.507914	-.0027	.3762	5.8815	0.0000	7.5534
22.216907	-.0027	.3716	6.5205	0.0000	7.5534
23.925900	-.0027	.3671	7.1518	0.0000	7.5534
25.634893	-.0027	.3625	7.7752	0.0000	7.5534
27.343886	-.0027	.3580	8.3909	0.0000	7.5534
29.052879	-.0027	.3534	8.9989	0.0000	7.5534
30.761872	-.0027	.3489	9.5990	0.0000	7.5534
32.470865	-.0027	.3443	10.1914	0.0000	7.5534
34.179857	-.0027	.3398	10.7759	0.0000	7.5534
35.888850	-.0027	.3352	11.3527	0.0000	7.5534
37.597843	-.0027	.3307	11.9218	0.0000	7.5534
39.306836	-.0027	.3261	12.4830	0.0000	7.5534
41.015829	-.0027	.3216	13.0365	0.0000	7.5534
42.724822	-.0027	.3170	13.5822	0.0000	7.5534
44.433815	-.0027	.3125	14.1201	0.0000	7.5534
46.142808	-.0027	.3079	14.6502	0.0000	7.5534
47.851800	-.0027	.3034	15.1726	0.0000	7.5534
49.560793	-.0027	.2988	15.6871	0.0000	7.5534
51.269786	-.0027	.2943	16.1939	0.0000	7.5534
52.978779	-.0027	.2897	16.6930	0.0000	7.5534
54.687772	-.0027	.2852	17.1842	0.0000	7.5534
56.396765	-.0027	.2806	17.6677	0.0000	7.5534
58.105758	-.0027	.2761	18.1433	0.0000	7.5534
59.814751	-.0027	.2715	18.6112	0.0000	7.5534
61.523743	-.0027	.2670	19.0714	0.0000	7.5534
63.232736	-.0027	.2624	19.5237	0.0000	7.5534
64.941729	-.0027	.2579	19.9683	0.0000	7.5534
66.650722	-.0027	.2533	20.4051	0.0000	7.5534
68.359715	-.0027	.2488	20.8341	0.0000	7.5534
70.068708	-.0027	.2442	21.2553	0.0000	7.5534
71.777701	-.0027	.2397	21.6687	0.0000	7.5534
73.486694	-.0027	.2351	22.0744	0.0000	7.5534
75.195686	-.0027	.2305	22.4723	0.0000	7.5534
76.904679	-.0027	.2260	22.8624	0.0000	7.5534
78.613672	-.0027	.2214	23.2448	0.0000	7.5534
80.322665	-.0027	.2169	23.6193	0.0000	7.5534
82.031658	-.0027	.2123	23.9861	0.0000	7.5534
83.740651	-.0027	.2078	24.3451	0.0000	7.5534
85.449644	-.0027	.2032	24.6963	0.0000	7.5534
87.158637	-.0027	.1987	25.0398	0.0000	7.5534
88.867629	-.0027	.1941	25.3754	0.0000	7.5534
90.576622	-.0027	.1896	25.7033	0.0000	7.5534
92.285615	-.0027	.1850	26.0234	0.0000	7.5534
93.994608	-.0027	.1805	26.3357	0.0000	7.5534
95.703601	-.0027	.1759	26.6403	0.0000	7.5534
97.412594	-.0027	.1714	26.9371	0.0000	7.5534
99.121587	-.0027	.1668	27.2260	0.0000	7.5534
100.830580	-.0027	.1623	27.5073	0.0000	7.5534
102.539572	-.0027	.1577	27.7807	0.0000	7.5534
104.248565	-.0027	.1532	28.0463	0.0000	7.5534
105.957558	-.0027	.1486	28.3042	0.0000	7.5534
107.666551	-.0027	.1441	28.5543	0.0000	7.5534
109.375544	-.0027	.1395	28.7966	0.0000	7.5534
111.084537	-.0027	.1350	29.0312	0.0000	7.5534
112.793530	-.0027	.1304	29.2579	0.0000	7.5534
114.502523	-.0027	.1259	29.4769	0.0000	7.5534
116.211515	-.0027	.1213	29.6881	0.0000	7.5534
117.920508	-.0027	.1168	29.8915	0.0000	7.5534
119.629501	-.0027	.1122	30.0872	0.0000	7.5534
121.338494	-.0027	.1077	30.2751	0.0000	7.5534
123.047487	-.0027	.1031	30.4551	0.0000	7.5534
124.756480	-.0027	.0985	30.6275	0.0000	7.5534
126.465473	-.0027	.0940	30.7920	0.0000	7.5534
128.174466	-.0027	.0894	30.9487	0.0000	7.5534
129.883458	-.0027	.0849	31.0977	0.0000	7.5534
131.592451	-.0027	.0803	31.2389	0.0000	7.5534
133.301444	-.0027	.0758	31.3723	0.0000	7.5534
135.010437	-.0027	.0712	31.4980	0.0000	7.5534
136.719430	-.0027	.0667	31.6158	0.0000	7.5534
138.428423	-.0027	.0621	31.7259	0.0000	7.5534
140.137416	-.0027	.0576	31.8282	0.0000	7.5534
141.846409	-.0027	.0530	31.9227	0.0000	7.5534
143.555401	-.0027	.0485	32.0095	0.0000	7.5534
145.264394	-.0027	.0439	32.0884	0.0000	7.5534
146.973387	-.0027	.0394	32.1596	0.0000	7.5534
148.682380	-.0027	.0348	32.2230	0.0000	7.5534
150.391373	-.0027	.0303	32.2787	0.0000	7.5534
152.100366	-.0027	.0257	32.3265	0.0000	7.5534
153.809359	-.0027	.0212	32.3666	0.0000	7.5534
155.518352	-.0027	.0166	32.3989	0.0000	7.5534
157.227344	-.0027	.0121	32.4234	0.0000	7.5534
158.936337	-.0027	.0075	32.4401	0.0000	7.5534
160.645330	-.0027	.0030	32.4491	0.0000	7.5534
162.354323	-.0027	-.0016	32.4502	0.0000	7.5534
164.063316	-.0027	-.0061	32.4436	0.0000	7.5534

NATURAL PERIOD 66.836586

MAXIMUM DEFLECTION 32.450250

TIME TO MAXIMUM DEFLECTION 164.063316

DURATION/NATURAL PERIOD .255697

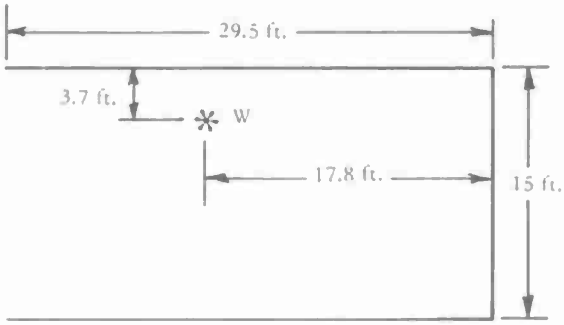
LOAD/RESISTANCE 18.651596

ELASTIC DEFLECTION LIMIT .301369

MAX FRAGMENT SPALL VELOCITY FT/SEC 32.134193

WALL COLLAPSES
AVERAGE SCAB VELOCITY 30.59
MAX SCAB VELOCITY 152.96

EXAMPLE 4 HAND CALCULATION [3]



H = 17 ft.
h = 4.2 ft.
h/H = 4.2/17 = 0.25

The design charge weights W are equal to the weight of explosive W_e times a 1.2 factor of safety times a TNT equivalency factor (e.g., Composition B has a factor of 1.13). The maximum design charge weight is:

$$W = W_e \times 1.2 \times 1.13 = 1{,}060 \times 1.2 \times 1.13 = 1{,}440 \text{ lb}$$

To determine the actual capability of the wall, it will be necessary to know blast impulse versus weight. The following impulse values are calculated from Reference 3. For the sidewall 3.7 feet from the weapon:

$N = 2$ (two adjacent reflective surfaces)

$l = 17.8$ ft

$h = 4.2$ ft

$R_a = 3.7$ ft

$L = 29.5$ ft

$H = 17$ ft

$L/R_a = 29.5/3.7 = 8.0$

$l/L = 17.8/29.5 = 0.60$

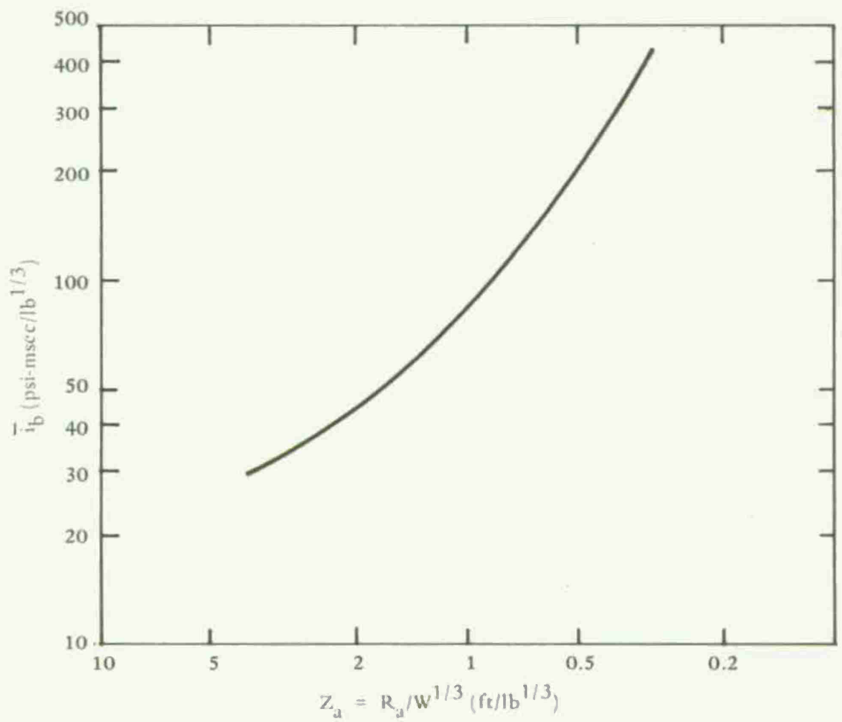
$L/H = 29.5/17 = 1.74$

$Z_a = R_a/W \text{ in.}^3 = 0.34$

Blast Impulse on Sidewall for Various Design Weights of Explosive

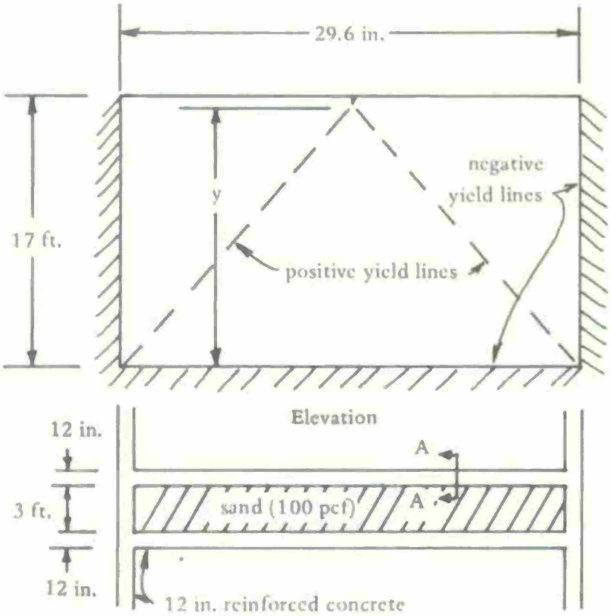
L/H	z_a	W	$\bar{i}_b$ (psi-msec/lb$^{1/3}$)		
			ℓ/L = 0.50	ℓ/L = 0.75	ℓ/L = 0.60*
1.50	0.35	1,181	320	280	304
	0.50	405	190	170	182
	0.75	120	112	100	107
	1.0	51	77	75	76
	1.5	15	54	49	52
	3.0	2	34	33	34
3.00	0.35	1,181	480	495	486
	0.50	405	300	280	292
	0.75	120	175	160	169
	1.0	51	118	110	115
	1.5	15	70	68	69
	3.0	2	34	32	33
174*	0.35	1,181			333
	0.50	405			200
	0.75	120			117
	1.00	51			82
	1.5	15			55
	3.0	2			34

* i_b values determined by linear interpolation.

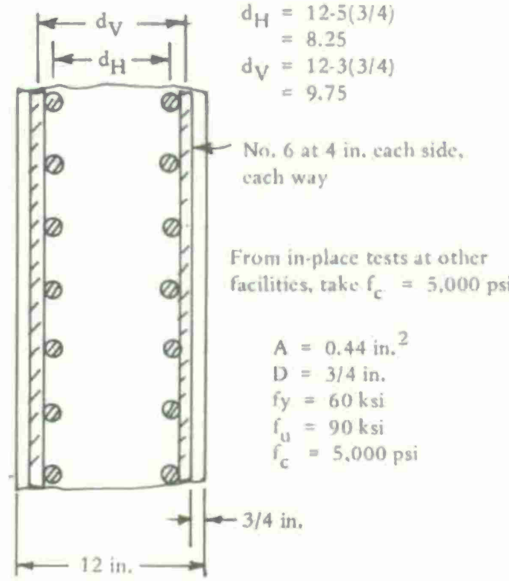


For 1,440 lb, $\bar{i}_b$ = 360 x 11.2 = 4,032 psi-msec

Sidewall Ultimate Moment Capacity With Three Edges Fixed



Sidewall Plan View



A–A

Ultimate Moment

For rectangular section of width b with compression reinforcement, A_s',

$$M_u = \frac{(A_s - A_s')f_s}{b}\left(d - \frac{a}{2}\right) + \frac{A_s'f_s}{b}(d-d')$$

$$f_s = f_y\ (DIF)$$

$$DIF = 1.20$$

$$\text{Since } A_s = A_s'$$

$$M_u = \frac{A_s'f_s}{b}(d-d')$$

$$M_{uH} = \frac{0.44(60{,}000 \times 1.20)(8.25)}{4} = 65{,}340 \text{ in.-lb/in.}$$

$$M_{uV} = \frac{0.44(72{,}000)(9.75)}{4} = 77{,}220 \text{ in.-lb/in.}$$

Yield Line Location

$$y/H = f\left[\frac{L}{H}\left(\frac{M_{VN} + M_{VP}}{M_{HN} + M_{HP}}\right)^{1/2}\right] = f\left[\frac{29.5}{17}\left(\frac{2 \times 77{,}220}{0.2 \times 65{,}340}\right)^{1/2}\right]$$

$$= f\left[1.74(1.087)\right] = f(1.89)$$

$$= 0.97$$

$$y = 0.97(17') = 16.5' = 198 \text{ in.}$$

Ultimate Resistance

$$r_u = \frac{5(M_{VN} + M_{VP})}{y^2} = \frac{5(2 \times 77{,}220)}{198^2} = 19.7 \text{ psi}$$

Maximum Deflection

For sections without laced reinforcement, a maximum support rotation of 2 degrees is all that can be counted on since buckling of the compression steel will occur at greated rotations.

$$x_m = \frac{L \tan \Theta_H}{2} = \frac{29.5 \times 12 \tan 2^{o}}{2} = 6.18 \text{ in.}$$

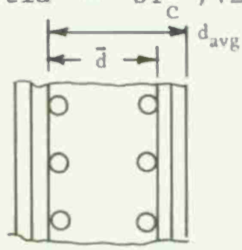
Section Properties - Modulus of Elasticity

$$E_c = 57{,}000\sqrt{f_c'} = 57{,}000\sqrt{5{,}000} = 4.03 \times 10^6 \text{ psi}$$

$$E_s = 29 \times 10^6$$

$$n = E_s/E_c = \frac{29 \times 10^6}{4.03 \times 10^6} = 7.19$$

For a 1-inch strip the gross moment of inertia $= bT_c^{\,3}/12$



$$I_g = \frac{12^3}{12} = 144 \text{ in.}^4$$

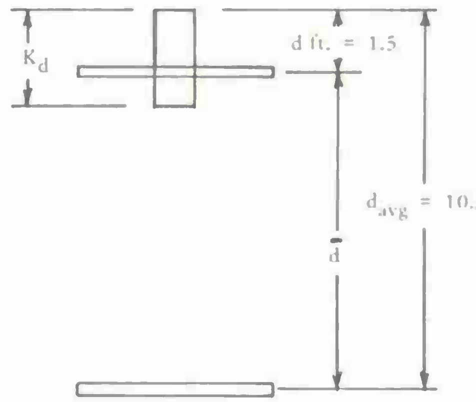
$$A_s/\text{in.} = \frac{0.44}{4} = 0.11 \text{ in.}^2/\text{in.}$$

$$\bar{d} = \frac{d_H + d_V}{2} = \frac{8.25 + 9.75}{2} = 9^{o} \text{ in.}$$

$$d_{avg} = 9 + \frac{(12-9)}{2} = 10.5 \text{ in.}$$

Moment of Inertia of Cracked Section

$$K_d = \frac{b(K_d)^2/2 + (n - 1)\, A'_s d' + nA_s d}{bK_d + (n - 1)\, A'_s + nA_s}$$



$b = 1$ inch

$A_s = A'_s = 0.11 \text{ in.}^2$

$n = 8.3$

$$K_d = \frac{(K_d)^2/2 + 7.3(.11)(1.5) + 8.3(.11)10.5}{K_d + 7.3(.11) + 8.3(.11)}$$

$$K_d = \frac{0.5(K_d)^2 + 1.20 + 9.59}{K_d + 0.80 + 0.91} = \frac{0.5(K_d)^2 + 10.79}{K_d + 1.71}$$

$$(K_d)^2 - 0.5(K_d)^2 + 1.71\, K_d - 10.79 = 0$$

$$(K_d)^2 + 3.42\, K_d - 21.58 = 0$$

$$K_d = \frac{-3.42 \pm \sqrt{(3.42)^2 + 4(21.58)}}{2} = \frac{-3.42 \pm 9.90}{2}$$

$$= 3.24 \text{ in.}$$

$$I_c = \frac{1(3.24)^3}{3} + 7.3(0.11)(3.24-1.5)^2 + 8.3(0.11)(10.5-3.24)^2$$

$$= 11.3 + 2.4 + 48.1 = 61.8 \text{ in.}^4/\text{in.}$$

Average Moment of Inertia

$$I_a = \frac{I_g + I_c}{2} = \frac{144 + 62}{2} = 103 \text{ in.}^4/\text{in.}$$

I_c by Approximation Method:

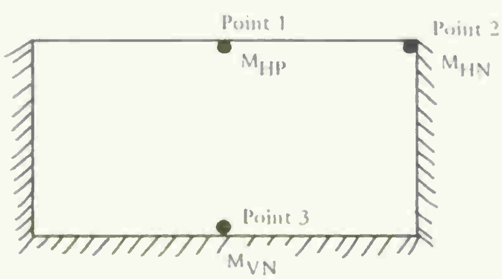
$$p = \frac{A_s}{b_d} = \frac{0.44}{4 \times 10.5} = 0.0105 \text{ in.}^2/\text{in.}$$

$$n = 7.2$$

$$F = 0.0465$$

$$\therefore I_c \simeq F_{bc}3 = 0.0465(1 \text{ in.})(10.5)^3 = 54 \text{ in.}^4/\text{in. versus } 61.8$$
calculated by transformed section

First Yield Point



$H/L = 17/29.5 = 0.58$
$\beta_1 = 0.092$
$\beta_2 = 0.215$
$\beta_3 = 0.17$
$\gamma_1 = 0.023$
$\nu = 1/6$

The deflection at the end of the elastic range of behavior, x_e, is determined from:

$$x_e D = \gamma r H^4$$

where $D = E_c I_a / b(1-\nu^2)$ and γ is obtained from the applicable figure. The point at which x_e occurs is determined from

$$M = \beta r H^2$$

which is used to see which point reaches M_u first.

Point 1.

$$M_{HP} = M_{uH} = 65,340 = \beta_1 r(17 \times 12)^2$$

$$r = \frac{65,340}{0.092(17 \times 12)^2} = 1.71 \text{ psi for Point 1 to reach } M_{HP}$$

Point 2.

$$M_{HN} = M_{uH} = 65,340 = \beta_2 r(204)^2$$

$$r = \frac{65,340}{0.215(204)^2} = 7.30 \text{ psi}$$

Point 3.

$$M_{VN} = M_{uV} = 77,220 = \beta_3 r(204)^2$$

$$r = \frac{77,220}{0.17(204)^2} = 10.9 \text{ psi}$$

Point 2 yields first at a pressure of 7.30 psi.

$$x_e = \frac{\gamma r H^4}{D}$$

$$D = \frac{E_c I_a}{b(1-\nu^2)} = \frac{3.49 \times 10^6 \times 103}{1(1-(1/6)^2)} = \frac{3.59 \times 10^8}{1(1-0.028)} = 3.69 \times 10^8$$

$$x_e = \frac{0.023(7.30)(204)^4}{3.69 \times 10^8} = 0.79 \text{ inch}$$

Second Yield Point

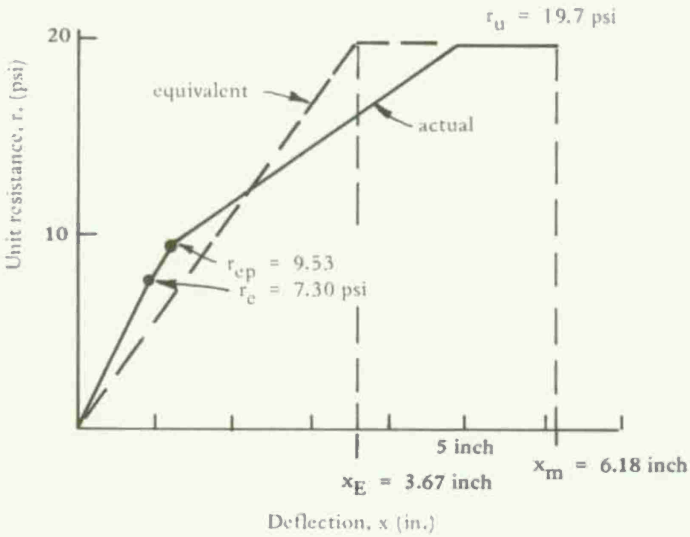
Since first yield occurs along the sides, both sides are now hinged, the bottom is fixed and the top free. For $H/L = 0.58$

$\gamma_1 = 0.044$

$\beta_1 = 0.121$

$\beta_3 = 0.275$

$$x_p = x_{ep} + \Delta x = 1.25 + 3.59 = 4.84 \text{ in.}$$



K_E = 19.7/3.67 = 5.36 psi/in.

Equivalent Resistance Deflection Curve

$$x_E = x_e(r_{ep}/r_u) + x_{ep}(1-r_e/r_u) + x_p(1-r_{ep}/r_u)$$

$$= 0.79(9.53/19.7) + 1.25(1-7.3/19.7) + 4.84(1-9.53/19.7)$$

$$= 3.67 \text{ in.}$$

Effective Masses

For the composite wall being analyzed, half the sand contained between the walls is taken with each wall when calculating the effective mass of each wall.

$$m = m_c + m_s = \frac{150 \times 10^6 t_c}{32.2 \times 1{,}728} + \frac{100 \times 10^6 t_s}{32.2 \times 1{,}728}$$

$$= 2{,}696(1) + 1{,}797(1.5) = 5{,}391 \text{ psi-msec}^2\text{/in.}$$

$$m_u = 0.51(5{,}391) = 2{,}749 \text{ psi-msec}^2\text{/in.}$$

M_{1e} at first yield $= 0.092\ (7.30)(204)^2 = 27{,}949$ in.-lb/in.

M_{3e} at first yield $= 0.17\ (7.30)(204)^2 = 51{,}645$ in.-lb/in.

ΔM_1 to second yield $= M_{uH} - M_{1e} = 65{,}340 - 27{,}949 = 37{,}391$

ΔM_3 to second yield $= M_{uV} - M_{3e} = 77{,}220 - 51{,}645 = 25{,}575$

<u>Point 1</u>

$$\Delta r_1 = \frac{\Delta M}{\beta_1\ (204)^2} = \frac{37{,}391}{0.121\ (204)^2} = 7.43$$

<u>Point 3</u>

$$\Delta r_3 = \frac{\Delta M_3}{0.275\ (204)^2} = \frac{25{,}575}{0.275\ (204)^2} = 2.23$$

$\therefore$ Point 3 reaches second yield at

$$r_{ep} = 7.30 + 2.23 = 9.53 \text{ psi}$$

$$\Delta x = \frac{\gamma \Delta r H^4}{D} = \frac{0.044(2.23)(204)^4}{3.69 \times 10^8} = 0.46 \text{ in.}$$

$$x_{ep} = x_e + \Delta x = 0.79 + 0.46 = 1.25 \text{ in.}$$

Third Yield Point

The three supported edges are now hinged; x_p will occur at r_u with γ and β.

$$\Delta r = r_u - r_{ep} = 19.7 - 9.53 = 10.2 \text{ psi}$$

for $L/H = 0.58$

$$\gamma_1 = 0.075$$

$$\beta_1 = 0.217$$

$$\Delta x = \frac{0.075(10.2)(204)^4}{3.69 \times 10^8} = 3.59 \text{ in.}$$

Effective Natural Period, T_n

$$T_n = 2\pi \frac{m_u}{K_E} = 2\pi = \frac{27.49}{19.7/3.67} = 142 \text{ msec}$$

Wall Response in Flexure

$$T_n = 142 \text{ msec}$$

Since there is no steel lacing, compression steel will buckle for $\Theta > 2$ degrees. Thus, the wall responds with limited deflection corresponding to $\Theta > 2$ degrees ($x_m < 6.18$ in.). If $t_m < 3\ t_o$ then the load can be considered as an impulse.

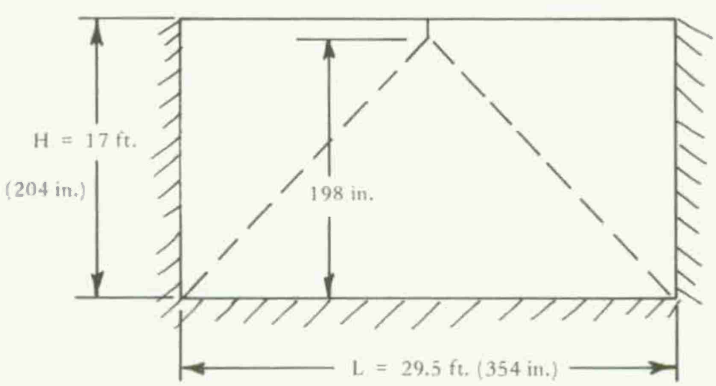
$$\frac{i_b^{\ 2}}{2m_a} = \frac{r_u x_E}{2} + \frac{m_a}{m_u} r_u\ (x_m - x_E)$$

$$i_b^{\ 2} = 2(3207)\ \left[\frac{19.7(3.67)}{2} + \frac{3207}{2749}\ (19.7)(6.18 - 3.67)\right]$$

$$i_b^{\ 2} = 601{,}856$$

$$i_b = 776 \text{ psi-msec}$$

Shear Loads and Capability



y/H = 0.97

Maximum Support Shear

$$V_{sH} = \frac{3r_u L(2-y/H)}{2(6 - y/H)} = \frac{3(19.7)(354)(2 - 0.97)}{2(6 - 0.97)} = 2,142 \text{ lb/in.}$$

$$V_{sV} = \frac{3r_u y}{5} = \frac{3(19.7)(198)}{5} = 2,340 \text{ lb/in.}$$

$$V_d = 0.18 f_c' \, bd = 0.18(4,000)(1)(10.5) = 7,560 \text{ lb/in.}$$

Support shear (2,142 and 2,340) < Direct shear capability (7,550)

Maximum Shear at d_c From Support

$$v_{uH} = \frac{3r_u(1 - 2\, d_c/L)(2 - y/H - 2\, d_c y/LH)}{2d_c/L(6 - y/H - 8\, d_c y/LH)}$$

$$= \frac{3(19.7)(1 - 2 \times 10.5/354)(2 - 0.97 - 2 \times 0.03 \times 6.97)}{2(.03)(6 - 0.97 - 8 \times 0.03 \times 0.97)}$$

$$= 188 \text{ psi}$$

$$v_{uV} = \frac{3r_u(1 - d_c/y)^2}{d_c/y(5 - d_c/y)} = \frac{3(19.7)(1 - 10.5/198)^2}{10.5/198(5 - 4 \times 10.5/198} = 220 \text{ psi}$$

$$m_c = 0.85(1.9 \quad 4,000 + 2,500 \times .0105) = 128.4 < v$$

Building ______________________ Date ________ Page 2

Card Format For Computer Program

Card	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71	72	73	74	75–80
1	Heading	EXAMPLE 4						Flag 0 or 1 *				
	1 10	11 20	21 30	31 40	41 50	51 60	61 70	71	72	73	74	80
2	W lb	Explo number	l/d ratio	case/explo	P amb psia	T amb °C	Altitude kft					
	1410.	1.	0.									
3	R_a ft/i psi ms*	H ft	L ft	h ft/PO psi*	ℓ ft/t_o ms*	t sand		F	R	L	R	
	3.7	17.	24.5	4.2	11.7	3.		1	0	0	1	
4	F_{dc} psi	F_{dy} psi	T_c in.	Theta O	N side							
	5000.	72000.	12.	2.	3							
5	A_sVT in.^{2}/ft	A_sVB in.^{2}/ft	A_sHT in.^{2}/ft	A_sHB in.^{2}/ft	D'VT in.	D'VB in.	D'HT in.	D'HB in.				
	1.32	1.32	1.32	1.32	1.125	1.125	1.125	1.125				

Example 4. Computer Analysis.

```
 T E S T   C A S E    E X A M P L E  4
TNT
EXPLOSIVE PROPERTIES.....CHARGE WEIGHT(LB) =    1440
NUMBER EQWT   EFORM EXPLOSIVE COMPOSITION BY WEIGHT
              KCAL/G      C      H      N      O     AL
   1  1.000 -.078400  .370  .022  .185  .423 0.000
PAMB(PSIA)=  14.69       TAMB(C)=  20.00
.....CASE WEIGHT CORRECTION IS CRUDE.  PSI EXCEEDS  RANGE OF EXPERIMENTAL DATA.

SHOCK WAVE CALCULATION
INPUT PARAMETERS                          CHARGE WEIGHT ADJUSTMENTS
CHARGE WEIGHT(LB)       =     1440        ADJUSTED WT(LB TNT)  =     1440
EXPLOSIVE NUMBER        =       1         HE ENERGY FACTOR     =   1.000
L/D RATIO               = -0.             CHARGE SHAPE FACTOR  =   1.000
CASE/CHARGE WT RATIO    = -0.             CASE WEIGHT FACTOR   =   1.000
CHAMBER PRESSURE(PSIA)=    14.69          PRESSURE SCALE FACTOR=   1.000
CHAMBER TEMP(C)         =    20.00        DISTANCE SCALE FACTOR=  8.8542E-02
ALTITUDE (KFT)          = -0.             TIME SCALE FACTOR    =  8.9307E-02
                                          NORMAL REFL FACTOR   =   10.99
DESIRED DISTANCE(FT)    =    3.700
                (CM)    =    112.8
 TIME AFTER  TIME AFTER   INCIDENT    NORM REFL
 EXPLOSION   SHOCK ARR   OVERPRESS   OVERPRESS
  (MSEC)      (MSEC)       (PSI)       (PSI)
   .1088      0.            3701      40.6646E+03
   .2802       .1714        1167      12.8256E+03
   .3659       .2571       735.5        8081
   .4515       .3427       477.6        5248
   .5372       .4284       312.4        3433
   .6229       .5141       201.3        2212
   .7086       .5998       124.0        1363
   .7943       .6855       68.92       757.3
   .8800       .7712       29.07       319.4
   .9657       .8569      0.           0.
IMPULSE (PSI.MSEC)--
    INCIDENT =    634.2
    REFLECTED=     6968
.....CAUTION--CONTACT SURFACE HAS ARRIVED.
        DATA ARE CRUDE BEYOND T(MSEC) AFTER SHOCK ARRIVAL= 10.7695E-03


                                                     INPUT


         DISTANCE OF CHARGE FROM BLAST WALL          FT.              3.70

         CHARGE WEIGHT                               LBS.          1440.00

         BLAST WALL HEIGHT                           FT.             17.00

         BLAST WALL LENGTH                           FT.             29.50

         HEIGHT OF CHARGE ABOVE GROUND               FT.              4.20

         MIN. DIST. BETWEEN CHARGE + ADJ. WALL       FT.             11.70

         REFLECTION CODE                                          1  0  0  1


         TOTAL  IMPULSE          3925.40 PSI-MS

         DURATION OF LOAD        5.41720  MSEC

         FICTITIOUS PEAK PRESSURE     1449.23502  PSI
```

```
DYNAMIC CONCRETE STRENGTH      5000.00
DYNAMIC STEEL STRESS          72000.00
THICKNESS CONCRETE  INCHES       12.0000
THICKNESS OF SAND   INCHES       36.0000
THETA ALLOWABLE     DEGREES       2.0000


AREA VERT TOP STEEL/FT           1.3200  COVER     1.1250
AREA VERT BOT STEEL/FT           1.3200  COVER     1.1250
AREA HORIZ TOP STEEL/FT          1.3200  COVER     1.8750
AREA HORIZ BOT STEEL/FT          1.3200  COVER     1.8750

CONCRETE MODULUS PSI                 4030509
RATIO MOD STEEL/CONCRETE           7.20
GROSS MOMENT INERTIA             144.00
AVE CRACKED MOM INERTIA           55.22
AVE MOMENT INERTIA                99.61
AVERAGE PERCENT STEEL             .0105
D FACTOR MU=1/6                           412963063
D FACTOR  MU= 0.3                         441189769


ALLOW SHEAR UNREINFORCED WEB      122.70  PSI          1288.31 LBS/IN WIDTH
ALLOW SHEAR AT SUPPORT            720.00  PSI          7560.00  LBS/IN WIDTH
UNREINFORCED CONCRETE   THETA LE 2 DEG

POSITIVE VERTICAL MOMENT      77220.00
NEGATIVE VERTICAL MOMENT      77220.00
POSITIVE HORIZONTAL MOMENT      65340.00
NEGATIVE HORIZONTAL MOMENT      65340.00


SUPPORT ON  3 SIDES

YIELD LINE  Y  ABOVE FLOOR

LOCATION YIELD LINE LENGTH        177.00
LOCATION YIELD LINE HEIGHT        195.39
ULTIMATE LOAD CAPACITY  RU      20.2274
HORIZ SHEAR LOAD AT SUPPORT            2220.10  LB/IN WIDTH
VERT SHEAR LOAD AT SUPPORT             2371.30  LB/IN WIDTH
HORIZ SHEAR AT DIST FROM SUPPORT        196.93  PSI
VERT SHEARAT DIST FROM SUPPORT          211.30  PSI
ALLOWABLE MAX DEFLECTION         6.1863


LOAD MASS FACTOR                  .5089
MASS CONCRETE ONLY              1371.91



FIRST YIELD POINT AT PT2
ELASTIC  LIMIT  RE PSI              7.35
ELASTIC DEFLECTION  XE            .7229



SECOND YIELD AT PT 3
ELASTO PLASTIC LIMIT              9.79
ELASTO-PLASTIC DEFLECTION        1.1505
ULTIMATE RESISTANCE              20.23
PLASTIC DEFLECTION               4.4639



ULTIMATE RESISTANCE RU         20.23
ELASTIC DEFLECTION LIMIT  XE       3.3859
STIFFNESS  KE                      5.97



NATURAL PERIOD              134.649555
IMPULSE CAPACITY ONE WALL        828.62
SCALLED IMPULSE CAPACITY          73.56
SCALED SAND THICKNESS             .2663
SCALED CONCRETE THICKNESS         .0888
```

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